Design and Impedance Modeling of Complementary Circular Loop FSS at 2.4GHz

Mohamad Zoinol Abidin Abd Aziz, Farhana Abu Hussin, Badrul Hisham Ahmad, Mohamad Kadim Suaidi and Noor Azamiah Md Fauzi
Center for Telecommunication Research and Innovation (CeTRI), Faculty of Electronic & Computer Engineering, Universiti Teknikal Malaysia Melaka (UTeM), Hang Tuah Jaya 76100, Durian Tunggal, Melaka, Malaysia.
mohamadzoinol@utem.edu.my

***Abstract*—This paper presents the design of a circular loop for Frequency Selective Surfaces (FSS) based on complementary techniques for 2.4GHz application. The design of circular loop FSS is simulated using CST Microwave Studio software. The simulation process is based on the characteristics of the reflection coefficient (S11) and transmission coefficient (S21) of the FSS. In this paper, there are two designs that have been presented, namely Design A, which is double circle loop in horizontal axes and Design B is double circle loop in horizontal axes using complementary techniques. It was found that the best performance of the FSS is Design B in terms of return loss and bandwidth. The return loss for Design B is -29.13dB and the bandwidth is 0.39211 GHz at a frequency range from 2.2012 GHz to 2.5933 GHz.**

***Index Terms*—Circular Loop; Frequency Selective Surface (FSS); Reflection Coefficient (S11); Transmission Coefficient (S21); Complementary Techniques.**

I. INTRODUCTION

Metamaterials have properties that may not be found in nature. The word ‘metamaterials’ is a combination of "meta" and "material"; Meta is a Greek word which means something beyond, altered, changed or something advanced as presented in [1]. In other meaning, Metamaterials can have their electromagnetic properties altered to something beyond what can be found in nature. They gain their properties not from their composition but from their designed structures. It consists of periodic structure and subwavelength characteristics where the particle is smaller than the light wavelength with which it interacts. Other structures that exhibit the subwavelength characteristics are Frequency Selective Surface (FSS) or also known as Artificial Magnetic Conductor (AMC) or High Impedance Surface (HIS) [1-2]. Frequency Selective Surface (FSS) is planar periodic structure of identical patches or apertures of conducting elements repeating periodically in either a one- or two-dimensional array on a dielectric substrate [3]. FSS is two-dimensional periodic arrays that can function as a spatial filter in free space which consists of two types of elements. The two types of element are patches elements and aperture element (slot). The different design elements of FSS can produce different results such as patch element that can produce band stop characteristic while the aperture element can produce the band pass signal [4].

FSS is planar periodic structure of identical array of patch or aperture type elements arranged in one or two-dimensional plane. FSS is designed on dielectric substrate. Bayatpur [1] mentioned that FSS acts like a spatial filter when it is exposed to electromagnetic radiation. FSS periodic arrays have inherent inductive and capacitive properties, combined to obtain the desired frequency response. FSS has filtering characteristics, which are bandpass and bandstop behaviours, as some of the frequency bands are transmitted, while some are reflected.

The technology of Frequency Selective Surface (FSS) has a long history of development. Over the past few decades, numerous applications for FSS have been found in both commercial and military sectors to provide multiple frequency band operation. Extensive analytic research has been performed to predict the reflection coefficient and transmission coefficient properties of FSSs [5-6].

II. FSS DESIGN

The proposed FSS is designed and simulated by using CST Microwave Studio. This structure has been designed on the FR4 material substrate with a thickness of 1.6mm, dielectric constants of 4.4 and loss tangent of 0.019. Meanwhile, the structure of FSS layer is made from copper material with a thickness of 0.035mm.

In this paper, there are two design types that have been investigated. All designs types are shown in Figure 1 and Figure 2. Design A is a combination of double circle loop in horizontal axes. Figure 2 shows Design B, which is a double circle loop in horizontal axes using complementary techniques.

The design parameters that have been identified for each design are the length of square loop with patch (s), square loop (a) and (d), outer circle loop with patch (b) and (f), and inner circle loop (c) and (g). This proposed FSS is suitable as a microwave band pass filter for WLAN 2.4GHz application.

Figure 3 shows the geometry of Design B for front view and back view. From the back view, first the square FSS, s, was designed on FR4. When parameter s is increased, the reflection coefficient shifted to the lower part of the frequency. Then the square loop FSS, a, was added to the FR4. Lastly, the circular conductive patch of FSS with length of c was added inside the square loop of FSS.

The patch dimension was calculated according to the formula in Equation (1).

The length of the patch, *s* is calculated by [8]:

$$s = \frac{c}{2f\sqrt{\varepsilon_{eff}}} - 2\Delta \tag{1}$$

where the effective dielectric constant is known as ε_{eff} and the length extension is Δ.

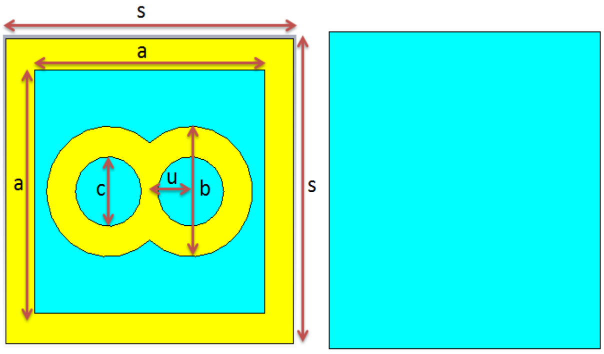


Figure 1: Design A (combination of double circle loop in horizontal axes)

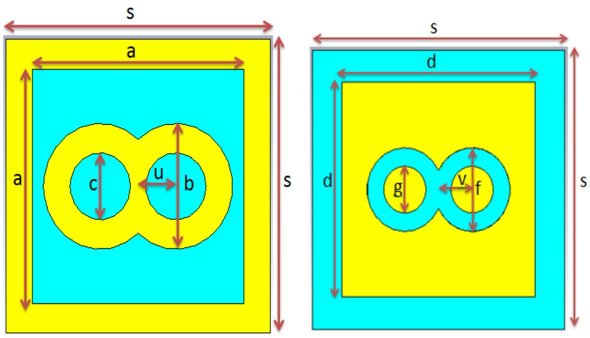
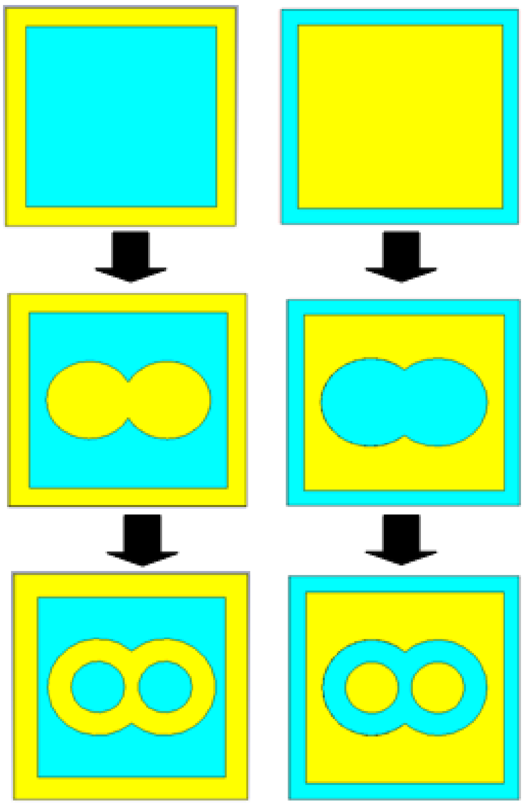


Figure 2: Design B (double circle loop in horizontal axes using complementary techniques)



(a) (b)

Figure 3: Geometry of Design B for the (a) front view (b) back view

Table 1
Design Parameters for Design B

Parameter	Dimension (mm)	Description
a	28	Length a
b	12	Radius b
c	8	Radius c
d	23	Length d
f	9	Radius f
g	5	Radius g
s	35	Substrate Length
tc	0.035	Copper Thickness
ts	1.6	Substrate Thickness
u	5	Distance from the center
v	4	Distance from the center

Based on the mathematical calculation, the width and length of the patch were calculated as *s*=35mm. Other parameters were defined by using parametric studies. The parametric studies were carried out by using CST MWS to investigate the effects of each design parameter. It seems that the performance of the FSS was influence by several parameters. Then, optimization was done to obtain the best performance of the FSS at frequency 2.4GHz. Other details of design parameter are shown in Table 1.

III. Result And Discussion

A. Simulation Result

The minimum reflection coefficient at frequency 2.4GHz was found in Design A, which is -27.08dB and bandwidth of 0.4799 GHz from frequency 2.1542 GHz to 2.6368 GHz. The maximum reflection coefficient was found in Design B which is -29.13dB and bandwidth of 0.39211 GHz from frequency 2.2012 GHz to 2.5933 GHz.

The minimum transmission coefficient was found in Design A which is -0.29dB. The maximum transmission coefficient was found in Design B which is -0.17dB. The details of comparison of reflection coefficient and transmission coefficient for all designs are shown in Table 2.

The simulation results of reflection coefficient (S11) and transmission coefficient (S21) for Design A and Design B that have been designed are presented in Figure 4 and Figure 5. Design A and Design B are simulated in the range frequency between 1GHz to 3GHz. The reflection coefficient at frequency 2.4GHz of Design B is -29.13dB dB with bandwidth of 0.39211 GHz. The transmission coefficient of Design B is -0.17dB.

B. Impedance Characteristics

By using the well-known circuit theory, the FSS can be equivalently modelled as a resonant circuit consisting of parallel-connected two series L-C resonator. Reflection coefficient can be represented as Γ which is the ratio of the amplitude of the reflected wave to the amplitude of the incident wave. The impedance at the load Z_L can be calculated by using Equation (2). Z_0 is the impedance of free space (376.7 Ω). The waveguide ports in the design represent the Z_0 [9]-[10].

$$\Gamma = \frac{Z_L - Z_0}{Z_L + Z_0} \quad (2)$$

Table 2
Reflection Coefficient and Transmission Coefficient for Design A and Design B

Designs	Reflection Coefficient (S11)	Transmission Coefficient (S21)	Bandwidth
Design A	-27.08dB	-0.29dB	0.4799 GHz
Design B	-29.13dB	-0.17dB	0.3921GHz

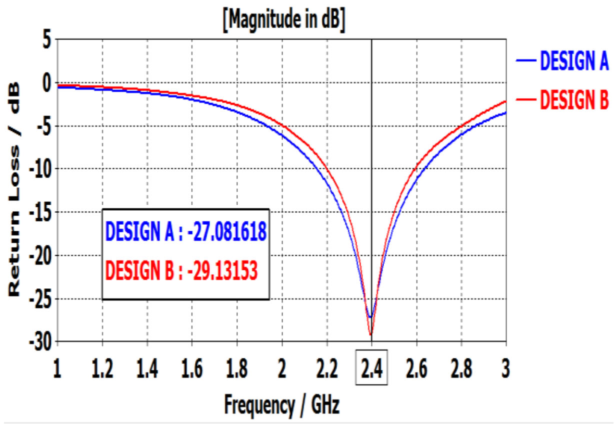


Figure 4: Reflection Coefficient (S11)

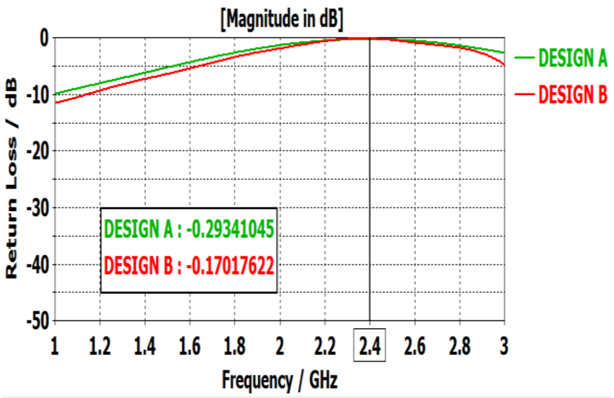


Figure 5: Transmission Coefficient (S21)

Table 3
Impedance Characteristic of Dielectric Substrate at 2.4GHz for Design A and Design B

Design	Impedance,ZL (Ω)
Design A	ZL = 407.83 + j15.44
Design B	ZL = 400.68 + j12.82

The impedance characteristic of dielectric substrate at 2.4GHz for Design A and Design B are shown in Table 3. The ranges of the resistance are between 400.68Ω to 407.83Ω. The reactance is said to be inductive. This impedance characteristic is very useful which can be used to design the equivalent circuit of the FSS.

In the Table 4 show the impedance modeling for the resistance of Design B. Meanwhile, Table 5 presents the reactance of the FSS for various parameters. The impedance is modeled by using polynomial type in Matlab for resistance and reactance of the impedance. The impedances were divided into certain ranges of length of physical dimension of FSS so that an accurate impedance modeling was produced based on the physical parameters. The highest degree of the resistance of all designs is 6th degree polynomial. The resistance modeling of all design is represented by (1) to (33).

The highest degree of the reactance of all designs is 6th degree polynomial. The resistance and reactance modeling of all design is represented by (1) to (33).

IV. Conclusion

This paper presented the design of a circular loop FSS for microwave transmission application at 2.4 GHz. There are two types of designs that have been presented in this paper. Design A is a combination of double circle loop in horizontal axes. Meanwhile Design B is a double circle loop in horizontal axes using complementary techniques.

The best performance of the designs is Design B in with the reflection coefficient is -29.13dB. Then, the impedance of each design was modeled by using mathematical modeling technique. The measurement process can be done in the future in order to compare and to validate the simulation results.

Acknowledgement

The authors would like to thank Universiti Teknikal Malaysia Melaka, (UTeM) for the support in obtaining the information and material for the development of our work. We also wish to thank anonymous referees whose comments led to an improved presentation of our work. Lastly, we would also like to thank the Ministry of Higher Education for TRGS/1/2014/FKEKK/02/1/D00001 research grant.

References

[1] Bayatpur, F. 2009. Metamaterial-Inspired Frequency-Selective Surfaces.
[2] Gangwar, K., & Gangwar, R. P. S. 2014. Metamaterials : Characteristics, Process and Applications, 4(1), 97–106.
[3] Mittra, R., Chan, C. H., & Cwik, T. 1988. Techniques for Analyzing Frequency Selective Surfaces-a Review. Proceedings of the IEEE, 76(12), 1593–1615. http://doi.org/10.1109/5.16352
[4] Singh, D., Kumar, A., Meena, S., & Agrawala, V. 2012. Analysis of Frequency Selective Surfaces for Radar Absorbing Materials. Progress In Electromagnetics Research B, 38(February), 297–314.
[5] Dubrovka, R., J. Vazquez, C. Parini, and D. Moore, 2006. Equivalent circuit method for analysis and synthesis of frequency selective surfaces, IEE Proceeding on Microwave Antennas Propagation, Vol. 153, No. 3, 213–220,
[6] Bukhari, S. S., Whittow, W. G., Vardaxoglou, J. C., & Maci, S. 2015. Square loop complementary frequency selective surfaces. IEEE Antennas and Propagation Society, AP-S International Symposium (Digest), 2015-October, 1258–1259.
[7] Hu, X. D., Zhou, X. L., Wu, L. S., Zhou, L., & Yin, W. Y. 2009. A miniaturized dual-band frequency selective surface (FSS) with closed loop and its complementary pattern. IEEE Antennas and Wireless Propagation Letters, 8, 1374–1377.
[8] Joshua, A., Singh, M., Mishra, M., & Sharma, P. 2013. Design & Optimization of Microstrip Patch Antenna Case. International Journal of Emerging Trends and Technology in Computer Science (IJETTCS), 2(5), 139–141.
[9] Aziz, N. A. F. M. Z. A. A., Said, M. A. M., Othman, M. A., Ahmad, B. H., & Malek, M. F. A. Investigation of Circle Loop Combination for Frequency Selective, 1–5.
[10] Qing, a., & Lee, C. K. 2001. An Improved Model for Full Wave Analysis of Multilayered Frequency Selective Surface with Gridded Square Element. Progress In Electromagnetics Research, 30, 285–303.

Table 4
Impedance Modeling for Resistance for Design B

Parameter	Impedance Modeling		
	Resistance, ohm(Ω)	Length/Width (mm)	
a	$R = 0.08439a^5$	$0 < a < 1$	(1)
	$R = -12.39a^4$	$1 < a < 2$	(2)
	$R = 727.3a^3$	$2 < a < 3$	(3)
	$R =-2.136e4a^2 + 3.138e^5a - 1.844e^6$	$3 < a < 5$	(4)
b	$R = -0.478b^5$	$0 < a < 1$	(5)
	$R = 31.13b^4 - 806.1b^3 + 1.037 e4b^2 -6.629 e4^b$	$1 < a < 4$	(6)
	$R = 1.691 e^5$	$4 < a < 5$	(7)
c	$R = 0.03407c^5$	$0 < a < 1$	(8)
	$R = -1.304c^4$	$1 < a < 2$	(9)
	$R = 19.1c^3$	$2 < a < 3$	(10)
	$R = -134.8c^2 +457.1c-180.8$	$3 < a < 5$	(11)
d	$R = -1.974d^5$	$0 < a < 1$	(12)
	$R = 200.7d^4$	$1 < a < 2$	(13)
	$R = -8146d^3$	$2 < a < 3$	(14)
	$R = 1.65e5d^2$	$3 < a < 4$	(15)
	$R = -1.668e^6d$	$4 < a < 5$	(16)
	$R = 6.733e^6$	$a < 5$	(17)
f	$R = 0.8572f^5$	$0 < a < 1$	(18)
	$R = -14.81f^4$	$1 < a < 2$	(19)
	$R = 94.31f^3$	$2 < a < 3$	(20)
	$R = -269.8f^2$	$3 < a < 4$	(21)
	$R = 337.2f$	$4 < a < 5$	(22)
	$R = 247.8$	$a < 5$	(23)
g	$R = 1.2g^5$	$0 < a < 1$	(24)
	$R = -50.21g^4$	$1 < a < 2$	(25)
	$R = 830.7g^3$	$2 < a < 3$	(26)
	$R = -6792^{g2}$	$3 < a < 4$	(27)
	$R = 2.744 e^4 g$	$4 < a < 5$	(28)
	$R = -4.342 e^4$	$a < 5$	(29)
s	$R = -0.0803s^5$	$0 < a < 1$	(30)
	$R = 13.01s^4 - 841.9s^3 +2.719 e4s^2$	$1 < a < 3$	(31)
	$R = -4.381 e^5s$	$3 < a < 4$	(32)
	$R = 2.82 e^6$	$4 < a < 5$	(33)

Table 5
Impedance Modeling for Reactance for Design B

Parameter	Impedance Modeling		
	Reactance, ohm(Ω)	Length/Width (mm)	
a	$X = 0.09531a^5$	$0 < a < 1$	(1)
	$X = -13.84a^4$	$1 < a < 2$	(2)
	$X = 799.4a^3$	$2 < a < 3$	(3)
	$X = -2.292e^4a^2 + 3.258e^5a - 1.835e^6$	$3 < a < 5$	(4)
b	$X = -0.4073b^5$	$0 < a < 1$	(5)
	$X = 32.29b^4 - 994.9b^3 + 1.5 e^4b^2 -1.109e^5b$	$1 < a < 4$	(6)
	$X = 3.222 e^5$	$4 < a < 5$	(7)
c	$X = -0.2515c^5$	$0 < a < 1$	(8)
	$X = 7.776c^4$	$1 < a < 2$	(9)
	$X = -95.43c^3$	$2 < a < 3$	(10)
	$X = 582.1c^2 - 1760c + 2086$	$3 < a < 5$	(11)
d	$X = 5.456d^5$	$0 < a < 1$	(12)
	$X=-555.2d^4$	$1 < a < 2$	(13)
	$X = 2.256 e^4d^3$	$2 < a < 3$	(14)
	$X = -4.574e^5d^2$	$3 < a < 4$	(15)
	$X = 4.628e^6d$	$4 < a < 5$	(16)
	$X = -1.869e^7$	$a < 5$	(17)
f	$X = -3.08f^50$	$0 < a < 1$	(18)
	$X = 54.15f^4$	$1 < a < 2$	(19)
	$X = -352.4f^3$	$2 < a < 3$	(20)
	$X = 1036f^2$	$3 < a < 4$	(21)
	$X = -1335f$	$4 < a < 5$	(22)
	$X = 631.6$	$a < 5$	(23)
g	$X = -4.008g^5$	$0 < a < 1$	(24)
	$X = 167.7g^4$	$1 < a < 2$	(25)
	$X = -2773g^3$	$2 < a < 3$	(26)
	$X = 2.266 e^4 g^2$	$3 < a < 4$	(27)
	$X = -9.146 e^4g$	$4 < a < 5$	(28)
	$X = 1.46 e^5$	$a < 5$	(29)
s	$X = 0.4391s^5$	$0 < a < 1$	(30)
	$X = -71.27s^4 +4622s^3 - 1.497e^5s^2$	$1 < a < 3$	(31)
	$X = 2.421 e^6 s$	$3 < a < 4$	(32)
	$X = -1.564 e^7$	$4 < a < 5$	(33)